STRATEGY RESEARCH PROJECT

OVERVIEW OF EMERGING ENVIRONMENTAL TECHNOLOGIES

BY

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Overview of Emerging Environmental Technologies

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ABSTRACT

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DOD is executing environmental restoration projects in accordance with compliance regulations from many federal agencies. With the passage of amendments to the Superfund law in 1986 that stated a preference for treatment instead of disposal, demand developed for alternative methods that provided more permanent and less costly solutions for dealing with contaminated materials. The Army files environmental impact statements on major programs and specific projects that are currently affecting, or have the potential to affect the environment. Personnel conducting those studies may find it helpful to learn about current environmental assessment methods and the outcomes of previous environmental studies. The Army currently spends almost 2.4% of its total budget on environmental programs. As the future budget picture continues to decline, new technologies offer the potential to provide a lower cost means of achieving the same level of environmental protection. This paper will provide an overview of environmental restoration planning and procedures, discuss information capabilities available on the Internet, provide summaries of recent technological literature and field studies; and identifies areas of informational "gaps". It concludes by urging closer ties between industry and the Army, as well as the need to pursue new and innovative techniques to solve old problems.

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OVERVIEW OF EMERGING ENVIRONMENTAL TECHNOLOGIES

The Department of Defense is responsible for cleaning up environmental contamination at more than 27,000 sites at over 10,000 installations and properties across the country and in the U.S. territories, resulting from decades of operations.[1] Much of this contamination involves land disposal of explosives and energetics-related wastes; petroleum, oils, and lubricants (POL); industrial solvents; and other military unique contaminants.

The cost to complete the DOD Cleanup Program is currently estimated to be $35 billion[2]. The Army's formal environmental cleanup efforts began in 1975 under the Army's Installation Restoration Program (IRP). Over time, environmental laws and regulations have required more systematic and far-ranging environmental cleanup efforts. The Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly known as Superfund, in 1980. This law governs cleanups of both federal and nonfederal hazardous waste sites.[3] In 1986, the Superfund Amendments and Reauthorization Act (SARA) formally established the Defense Environmental Restoration Program (DERP). The Deputy Under Secretary of Defense for Environmental Security (DUSD (ES)) is charged with oversight and management of the DERP[4], while the military components and agencies execute DOD's environmental cleanup program. The program goal of the DERP is to contain, treat or remove contamination so that it no longer poses a threat to public health and the environment, and restore the contaminated sites for productive use. Some of the specific policies identified to accomplish this goal include: remediation of contamination where appropriate; taking immediate action to remove imminent threats to health; developing partnerships with US Environmental Protection Agency (EPA); and supporting the development and use of cost-effective innovative technologies and process improvements in the restoration process.[5]

How is the Army going to support its mandated environmental restoration programs in this era of dwindling resources? How are commanders going to be kept abreast of changes in innovative technologies that affect their ability to manage their restoration programs?

This paper provides a brief overview of the planning processes involved in identifying an environmental restoration project. It specifically highlights those areas of innovative technologies that will affect the direction of a specific identified remedy at a specific site. It highlights those projects that are in the development or pilot program phase, and provides results of recent field-testing (to include cost savings). The paper also provides the reader with a compendium and discussion of Internet resources to further explore technological applications for each particular environmental problem.

DESIGN A CLEAN-UP PROGRAM

The process of investigating contamination at a site, determining how best to clean it up, and then performing the cleanup can be complex. There are several steps in the identification and cleanup process of a suspected environmental site. The commander will usually direct a preliminary assessment and site inspection to determine the likelihood of contamination and possible sources. Once contamination is

identified, a remedial investigation (RI) may be initiated to determine the extent of contamination present, or a feasibility study (FS) to evaluate and select proposed remedial options, such as new technologies. The next step would include the actual remedial action, which includes the design, construction, and operation of the selected remedy; long-term monitoring to measure the continued effectiveness of the cleanup activities; and site closeout when the appropriate regulatory agency has agreed that the cleanup process is complete.

During the RI/FS stage, the installation environmental program managers will design a program that will accomplish the remediation goals in the most cost-effective manner. Prior to the early 80's, the preferred approach to eliminate a hazardous waste from a particular location was to move it somewhere else, or cover it with a cap. These methods used land disposal as the solution to the problem. With an increasing number of cleanups underway, and the passage of amendments to the Superfund law in 1986 that stated a preference for treatment instead of disposal, demand developed for alternative methods that provided more permanent and less costly solutions for dealing with contaminated materials. Even though development and use of more suitable treatment technologies has progressed, one of the distinctive attributes of environmental technology is that state-of-the-art continually changes. Federal agencies have periodically updated and published information on remediation technologies in an effort to keep pace with these changes. However, government environmental program managers must often sort through large volumes of related and overlapping information to evaluate alternative technologies. As knowledge about the success or failure of innovative cleanup actions at contaminated sites increases, new methods for more effective, permanent cleanups will become available and must be shared within the environmental community. Publication of innovative treatment technology remediation information on the Internet has added a new dimension to the amount of accessible information. Several organizations now publish and manage Internet websites that purport to combine the unique features of several agency publications into a single website with extensive links to other remediation technology websites. However, the majority of these document technology innovations from the 1994-1996 period (or even earlier). Most do not provide the extensive documentation necessary to make them a standard choice in the engineering/scientific community. What they do however, is provide another source (dated though it may be) of information for the environmental community to pursue questions based on contamination problems as well as identified technology issues.

DOD is working to identify and develop permanent cleanup technologies and efficient and cost-effective waste site investigation techniques. Specifically, the DOD is looking to demonstrate emerging technologies, using generic remedies to address common pollutants and removing regulatory or statutory impediments to successful cleanup demonstrations and programs. One of the most critical elements will be to emphasize innovative technology development demonstration and validation. In order to succeed, the defense environmental technology community must develop strong partnerships with industry, community stakeholders and others scientists.

ONLINE INNOVATIVE TREATMENT TECHNOLOGY LISTINGS

One of the ways we can share information on success and failure of environmental programs is through online resources provided by various sources through government and industry. While most of the information contained in these resources below cannot be considered state-of-the-art, they are periodically updated by groups throughout the DOD. The listings below provide a general discussion of the capabilities each service provides, as well as identification of those resources that should be used when looking for a specific environmental remedy. I found the U.S. Army Environmental Center's (USAEC) Remediation Technologies Screening Matrix and Reference Guide, Third Edition to contain the most easily understood matrix of remedies, but some of the information was dated. The update to the system should bring the matrix in line with other, more recent information.

The EPA maintains a system called Remediation and Characterization Innovative Technologies (EPA REACH IT) to search, view, download and print information about innovative remediation and characterization technologies. [6] EPA REACH IT provides information about more than 750 service providers that offer almost 1,300 remediation technologies and more than 150 characterization technologies. EPA REACH IT combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT). It also describes recent field demos, commercial applications and research on technologies to allow users to consider new, less costly, and more effective technologies for environmental remediation. This service provides the DOD user with invaluable EPA information and resources.

EPA's policy Reinvention for Innovative Technologies (ReFIT) program is to strengthen incentives for the development and use of promising new technologies. ReFIT was established under the Environmental Technology Initiative (ETI), an EPA-led interagency program to improve public health and environmental protection by removing barriers to technology innovation.

EPA maintains the Alternative Treatment Technology Information Center (ATTIC), which is an information retrieval network that provides site remediation managers with technical information on alternative treatment methods for remediating hazardous waste. The database contains abstracts from more than 2,000 technical references, include books, EPA publications, journal articles, and treatability studies.[7]

The EPA Technology Transfer Network (TTN) is a collection of technical Web sites containing information about many areas of air pollution science, technology, regulation, measurement, and prevention.[8]

EPA also maintains the Bioremediation in the Field Search System (BFSS), which provides access to database of information on waste sites across the country where bioremediation is being tested or implemented or has been completed. BFSS currently provides information on ex situ and in situ technologies at more than 160 bioremediation sites nationwide.[9] The database includes full-scale

remediation efforts and treatability studies that cover sites under EPA's authority. This information is not accessible via the Internet; you must request a copy of the information by mail.

EPA maintains the Hazardous Waste Superfund Collection Database, which provides an online bibliographic data base corresponding to a special collection of hazardous waste documents located throughout the EPA library network. The system includes bibliographic references and abstracts on EPA reports, policy and guidance directives, legislation, regulations, and non-government books.[10]

Business Gold is an electronic bulletin board system operated by the National Technology Transfer Center (NTTC) to provide access to the latest information on the newest technologies available through the research and development program of Federal government agencies.[11] Business Gold provides a directory of Federal laboratory resources, current assistance program solicitations, state technical assistance program, regional technology transfer centers, current news and announcements, technology transfer conference calendar, Government software information centers, searchable databases, and User guides.

DTIC maintains the Defense RDT&E Online System which provides information on DOD's ongoing research and technology efforts. The system provides access to three separate databases: Research Work Unit Information System, Technical Report database, and Independent Research and Development database.[12]

DOE also maintains the Environmental Technologies Remedial Actions Data Exchange (EnviroTRADE) program which is designed to help facilitate the exchange of environmental restoration and waste management technologies. The system contains information (not online yet) on international environmental restoration and waste management technologies, organizations, sites, activities, funding, and contacts.

DOE maintains their Preferred Alternatives Matrix[13] as part of an effort by DOE's Environmental Restoration (EM-40) to provide a tool for field elements when selecting a technology remedy.

The Global Network of Environment & Technology (GNET) was created to promote the commercialization of innovative environmental technologies by decision-makers and facilitate development of the national environmental technology strategy. GNET features Environment & Technology News Briefs, Environment & Technology Business Forum, and Environment & Technology Information.[14]

The Corps of Engineers maintains the Defense Environmental Network Information (DENIX) system to provide DOD personnel information on environmental, legislative, compliance, restoration, cleanup, and DOD guidance information.[15] DENIX provides the capability to review environmental publications online, send and receive electronic mail via DENIX host and the Internet, and enter the interactive discussion forums on various subjects.

The U.S. Army Environmental Center (USAEC) is leading an effort to update the Remediation Technologies Screening Matrix and Reference Guide, Third Edition[16] under the auspices of the Federal Remediation Technologies Roundtable (FRTR). The Federal Remediation Technology Roundtable

(FRTR) was established in 1991 as an interagency committee (DOD, DOE, DOI, and EPA) to exchange information and to provide a forum for joint action regarding the development and demonstration of innovative technologies for hazardous waste remediation. The purpose of the update is to create a comprehensive "Remediation Technologies Yellow Pages" for use by those responsible for environmental cleanup. The Guide provides a listing of commonly recognized remediation technologies and provides users with a "one-stop-shopping" arena to make preliminary technology selection decisions. This reference guide provides essential descriptive information on the respective technologies, incorporates cost and performance data, and focuses primarily on demonstrated technologies. A detailed technology and synonym list is also available.

The USAEC also maintains a technology link for remediation technology currently being demonstrated, validated, and tested on Army installations. Current postings include composting and bioslurry technologies to treat soil that contains explosives, advanced oxidation technology to remove residues of explosives from groundwater, and soil washing/leaching technology to remove heavy metals.[17].

The USAEC maintains the Installation Restoration Data Management Information System (IRDMIS) which supports technical and managerial requirements of the Army's Installation Restoration Program and other environmental efforts.[18] The database contains analytical results from chemical, geotechnical, and radiological sampling.

U.S. Air Force Air Force Center for Environmental Excellence contains documents on the Air Force's major remediation initiatives including a hierarchy of preferred remediation alternatives, information on bioventing, bioslurper, natural attenuation, the risk-based approach and a cost-and-performance report on vapor-phase treatment.[19]

The Ground-Water Remediation Technologies Analysis Center offers a hierarchy of technical and information reports on ground-water remediation technologies and related topics. GWRTAC was established in 1995 and is operated by Concurrent Technologies Corporation, in association with the University of Pittsburgh's Environmental Engineering Program, under a Cooperative Agreement with the U.S. EPA Technology Innovation Office.[20]

INNOVATIVE REMEDIATION TECHNOLOGIES

The following discussion of innovative treatment technologies is organized to provide the reader with a compilation of remediation strategies that are currently in the full development or pilot phase. Where a solution has recently been tested (or is in the testing phase) I have highlighted the success resulting at that site. The discussion is organized initially by the medium to be treated, and then highlights different methods to treat the contamination in that medium. Since there is no "one best answer" for all environmental problems, you will need to identify the medium and contamination, and develop your restoration strategy from there. The technologies identified are split between the biological, chemical, or physical processes applied to hazardous waste or contaminated materials to permanently change their condition. Treatment technologies are designed to destroy contaminants or change them so that they are

no longer hazardous or, at least, are less hazardous. They may reduce the amount of contaminated material at a site, remove the component of the waste that makes it hazardous, or immobilize the contaminant within the waste. Treatment of contaminated sludges and soils is a field of technology that has developed and grown since Congress passed the "Superfund" law for contaminated waste site cleanup in 1980.[21] Three primary strategies used separately or in conjunction to remediate most sites are destruction or alteration of contaminants; extraction or separation of contaminants from environmental media; or immobilization of contaminants.

Treatment technologies that destroy contaminants by altering their chemical structure are thermal, biological, and chemical treatment methods. These destruction technologies can be applied in situ (in the natural or original position) or ex situ (removed from site or place) to contaminated media. The main advantage of in situ treatment is that it allows soil to be treated without being excavated and transported, resulting in potentially significant cost savings. However, in situ treatment generally requires longer time periods, and there is less certainty about the uniformity of treatment because of the variability in soil and aquifer characteristics and because the process is more difficult to verify. Generally, no single technology can remediate an entire site. Several treatment technologies are usually combined at a single site to form what is known as a treatment train.

Treatment technologies commonly used for extraction and separation of contaminants from environmental media include soil treatment by thermal desorption, soil washing, solvent extraction, and soil vapor extraction (SVE) and ground water treatment by either phase separation, carbon adsorption, air stripping, ion exchange, or some combination of these technologies.

Immobilization technologies include stabilization, solidification, and containment technologies, such as placement in a secure landfill or construction of slurry walls. No immobilization technology is permanently effective, so some type of maintenance is desired. Stabilization technologies are often proposed for remediating sites contaminated by metals or other inorganic species.

Bioremediation techniques are destruction techniques directed toward stimulating the microorganisms to grow and use the contaminants as a food and energy source by creating a favorable environment for the microorganisms. Generally, this means providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process.

Biological processes are typically implemented at low cost. Contaminants can be destroyed, and often little to no residual treatment is required. However, the process requires more time, and it is difficult to determine whether contaminants have been destroyed. Although not all organic compounds are amenable to biodegradation, bioremediation techniques have been successfully used to remediate soils, sludges, and ground water contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bioremediation is not applicable for treatment of inorganic contaminants.

Bioremediation is a treatment process that uses naturally occurring microorganisms (yeast, fungi, or bacteria) to break down, or degrade, hazardous substances (fuels and solvents) into less toxic or nontoxic substances (Carbon dioxide and water). It is a cost effective, natural process and uses naturally occurring microorganisms to break down hazardous substances into less toxic or nontoxic substances. Bioremediation can take place under aerobic and anaerobic conditions. In aerobic conditions, microorganisms use available atmospheric oxygen in order to function. With enough oxygen, microorganisms will convert many organic contaminants to carbon dioxide and water. Anaerobic conditions support biological activity in which no oxygen is present so the microorganisms break down chemical compounds in the soil to release the energy they need. Bioremediation can be used as a cleanup method for contaminated soil and water. Bioremediation techniques are destruction techniques directed toward stimulating the microorganisms to grow and use the contaminants as a food and energy source by creating a favorable environment for the microorganisms. Generally, this means providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process. Typical costs for enhanced bioremediation range from $30 to $100 per cubic meter ($20 to $80 per cubic yard) of soil. Variables affecting the cost are the nature and depth of the contaminants, and use of bioaugmentation.[22]

In Situ Bioremediation of Soil

In situ techniques do not require excavation of the contaminated soils, so they may be less expensive, create less dust, and cause less release of contaminants than ex situ techniques. Also, it is possible to treat a large volume of soil at once. In situ techniques, however, may be slower than ex situ techniques, may be difficult to manage, and are most effective at sites with sandy or uncompacted soil. The goal of aerobic in situ bioremediation is to supply oxygen and nutrients to the microorganisms in the soil. Two such methods are bioventing and injection of hydrogen peroxide. Oxygen can be provided by pumping air into the soil above the water table (bioventing) or by delivering the oxygen in liquid form as hydrogen peroxide. In situ bioremediation may not work well in clays or in highly layered subsurface environments because oxygen cannot be evenly distributed throughout the treatment area. In situ remediation often requires years to reach cleanup goals, and long-term monitoring will definitely be one of your restrictions.

Bioventing

Bioventing systems deliver air from the atmosphere into the soil above the water table through injection wells placed in the ground where the contamination exists. An air blower may be used to push or pull air into the soil through the injection wells. Air flows through the soil and the microorganisms use the oxygen in it. Nutrients may be pumped into the soil through the injection wells. Nitrogen and phosphorous may be added to increase the growth rate of the microorganisms. The U.S. Air Force Bioventing Initiative is demonstrating that this technology is effective under widely varying site conditions. Initial testing has

been completed at 117 sites, with more than 90 pilot systems now operating at 41 USAF installations[23]. On smaller sites, many of these single-well pilot systems are providing full-scale remediation. Regulatory acceptance of this technology has been obtained in 30 states and in all 10 EPA regions, and the use of this technology in the private sector is growing rapidly following USAF leadership. Bioventing is a medium to long-term technology. Cleanup ranges from a few months to several years. Based on the Air Force Center for Environmental Excellence (AFCEE) and commercial applications of this technology, costs for operating a bioventing system typically are $10 to $70 per cubic meter ($10 to $50 per cubic yard). This technology does not require expensive equipment and relatively few personnel are involved in the operation and maintenance of a bioventing system. Periodic maintenance monitoring is conducted.

Natural Attenuation

Natural Attenuation makes use of natural processes to contain the spread of contamination from chemical spills and reduce the concentration and amount of pollutants at contaminated sites. Natural attenuation—also referred to as intrinsic remediation, bioattenuation, or intrinsic bioremediation—is an in situ treatment method. Environmental contaminants are left in place while natural attenuation works on them. Natural attenuation is often used as one part of a site cleanup that also includes the control or removal of the source of the contamination.

In certain situations, natural attenuation is an effective, inexpensive cleanup option and the most appropriate way to remediate some contamination problems. Natural attenuation is sometimes mislabeled as a "no action" approach. However, natural attenuation is really a proactive approach that focuses on the confirmation and monitoring of natural remediation processes rather than relying totally on "engineered" technologies. Natural attenuation can be less costly than other active engineered treatment options, especially those available for ground water, and requires no energy source or special equipment. Natural attenuation is not an appropriate option at all sites. The rates of natural processes are typically slow, and long-term monitoring is necessary. Sites where the soil contains high levels of natural organic matter, such as swampy areas or former marshlands often provide successful conditions for natural attenuation. Certain geological formations such as fractured bedrock aquifers or limestone areas are less likely candidates for natural attenuation because these environments often have a wide variety of soil types that cause unpredictable ground water flow and make predicting the movement of contamination difficult.

Within the Superfund program, natural attenuation has been selected as one of the cleanup methods at 73 ground-water-contaminated sites—but is the sole treatment option at only six of these sites.[24] Some of these sites include municipal and industrial landfills, refineries, and recyclers. At the Allied Signal Brake Systems Superfund site in St. Joseph, Michigan, naturally occurring microorganisms are effectively removing TCE and other chlorinated solvents from ground water. EPA estimated the plume took about 20 years to move from the source of contamination to Lake Michigan—plenty of time for the microorganisms naturally present in the ground water to destroy the TCE without any outside intervention. In fact, microorganisms were destroying about 600 pounds of TCE a year at no cost to taxpayers. EPA determined that nature adequately remediated the TCE plume in St. Joseph.

Phytoremediation

Phytoremediation is the direct use of living green plants for in situ, or in place, risk reduction for contaminated soil, sludges, sediments, and ground water, through contaminant removal, degradation, or containment. Plants can break down, or degrade organic pollutants or contain and stabilize metal contaminants by acting as filters or traps. Growing and, in some cases, harvesting plants on a contaminated site as a remediation method is an aesthetically pleasing, solar-energy driven, passive technique that can be used to clean up sites with shallow, low to moderate levels of contamination. This technique can be used along with or, in some cases, in place of mechanical cleanup methods. Phytoremediation has been studied extensively in research and small-scale demonstrations, but full-scale applications are currently limited to a small number of projects. US AEC estimates that the cost for phytoremediation of one acre of lead-contaminated soil to a depth of 50 cm at $60,000 to $100,000, whereas excavating and landfilling the same soil volume was $400,000 to $1,700,000.[25]

A number of DOD installations have soils which will require remediation for heavy-metal contamination. Of the heavy metals, the DOD is currently emphasizing lead removal due to the inherent toxicity of lead and the quantity discharged. The contamination consists of both particulate and ionic metals. The metallic particulates (bullet fragments, etc.) were often deposited as the result of firing range use. The ionic metals were commonly deposited when metal-bearing propellants, ammunitions, and powders were burned at explosive disposal sites or when metal-bearing particulates in the soil were dissolved and converted into the ionic forms.

At sites contaminated with metals, plants are used to either stabilize or remove the metals from the soil and ground water through phytoextraction.

Phytoextraction

Phytoextraction refers to the uptake and translocation of metal contaminants in the soil by plant roots into the aboveground portions of the plants. Certain plants absorb unusually large amounts of metals in comparison to other plants. One or a combination of these plants is selected and planted at a particular site based on the type of metals present and other site conditions. After the plants have been allowed to grow for some time, they are harvested and either incinerated or composted to recycle the metals. This procedure may be repeated as necessary to bring soil contaminant levels down to allowable limits. Metals such as nickel, zinc, and copper are the best candidates for removal by phytoextraction because it has been shown that they are preferred by a majority of the approximately 400 known plants that uptake and absorb unusually large amounts of metals. Plants that absorb lead and chromium are currently being studied and tested.

The U.S. Army Environmental Center is leading a demonstration in the remediation of lead contaminated soil using the technique of phytoextraction. The team consists of Tennessee Valley Authority, Twin Cities Army Ammunition Plant, and Alliant Techsystems. The project goal is to determine the effectiveness of phytoextraction techniques for removing ionic lead from contaminated soils. The two-year field demonstration is currently being conducted at the Twin Cities Army Ammunition Plant (TCAAP)

in Arden Hills, Minnesota. During the phytoextraction process, water-soluble metals are taken up by plant species selected for their ability to take up large quantities of lead. The metals are stored in the plant's aerial shoots, which are harvested, and either smelted for potential metal recycling/recovery or are disposed of as a hazardous waste.

IN SITU PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES

Physical/chemical treatment

Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy, separate, or contain the contamination. Soil vapor extraction uses the contaminant's volatility to separate it from the soil. Soil flushing uses the contaminant's solubility in liquid to separate it from the soil. Available in situ physical/chemical treatment technologies include electrokinectic separation, soil vapor extraction, soil flushing, solidification/stabilization, and fracturing. Physical/chemical treatment is typically cost effective and can be completed in short time periods (in comparison with biological treatment). Equipment is readily available and is not engineering or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits. Stabilization/solidification technologies are less sensitive to soil parameters than other physical/chemical treatment technologies.

Military activities are one of the primary contributors to metals contaminated soil problems. Military operations such as small arms training, electroplating and metal finishing operations, explosive and propellant manufacturing and use, and the use of lead based paint on ships and at military facilities, have resulted in vast tracts of land being contaminated with metals. As a result, there is a military need to develop cost-effective remediation tools for cleaning up metals contaminated soils. Electrokinetics is a process that involves placing a series of anodes and cathodes in the soil. A low voltage current is applied across the electrodes resulting in current flow. As a result, metal and organic species move toward the electrodes where they can be extracted. Electrokinetic remediation is less destructive to ecologically sensitive areas and more cost effective than other metals removal technologies. Pilot scale demonstrations at USAEWES resulted in the removal of over 95% of the lead contained in the soil being treated. Several companies are currently working to develop electrokinetics as and in situ clean up method. USAEC will soon demonstrate and evaluated on a full-scale the electrokinetics process for the in situ removal of metal contaminants from soils. The demonstration site is an approximately ½ acre area in and around two waste pit lagoons located in a tidal salt marsh. The wastewater discharged into the unlined pits included approximately 95 million gallons of plating rinse water. Electrokinetics will provide the only available in situ treatment of metals contaminated soils. Cost savings of 40% to 90% are expected when compared to currently accepted cleanup methods. Also, there is the potential for the recovery of metals for recycling.

An electrokinetics demonstration project, jointly funded by the Environmental Security Technology Certification Program (ETSCP) and Naval Facilities Engineering Command, Southwest Division, is being

performed at Naval Air Weapons Stallion (NAWS) Point Mugu, California. The U.S. Army Environmental Center (USAEC) and U.S. Army Engineer Waterways Experiment Station (USAEWES) are conducting the demonstration

Soil Vapor Extraction and Air Sparging known as SVE, is the most frequently selected innovative treatment at Superfund sites. It is a relatively simple process that physically separates contaminants from soil. As the name suggests, SVE extracts contaminants from the soil in vapor form. SVE systems are designed to remove contaminants that have a tendency to evaporate easily. SVE removes volatile organic compounds and some semi-volatile organic compounds from soil beneath the ground surface in the unsaturated zone—that part of the subsurface located above the water table. By applying a vacuum through a system of underground wells, contaminants are pulled to the surface as vapor or gas. Often, in addition to vacuum extraction wells, air injection wells are installed to increase the airflow and improve the removal rate of the contaminant. An added benefit of introducing air into the soil is that it can stimulate bioremediation of some contaminants.

Enhanced soil vapor extraction (ESVE) adds heat and steam to a proven technology for removing volatile organic contaminants (VOCs) from permeable soils. The effectiveness of conventional SVE is limited when contaminants cannot be easily vaporized, if the soil is too tight for air to pass, or if the contaminants are below the water table. Heating the soil while venting can extend the effectiveness of SVE. Heating is done by injecting hot air or steam into the soil or by placing electrodes in the ground. The effectiveness of directly injecting hot air or steam depends largely on characteristics of the soil. Steam adds significant amounts of water to the subsurface. Where the contaminated zone is close to the water table, precautions must be taken to prevent the transfer of contaminants from soil to groundwater. Electrical heating is more applicable in tighter soils. Electrical heating not only raises the vapor pressure of the contaminants, but it also provides steam from soil moisture to accelerate removal of contaminants from soils. When electrical heating is sufficient to dry the soil, electrical conduction stops because dry soil is much more resistive. Water can be added to maintain conduction

Thermal treatment offers quick cleanup times, but it is generally the most costly treatment group. Cost is driven by energy and equipment costs and is both capital and O&M-intensive. Thermally enhanced SVE is an extraction technique that uses temperature to increase the volatility of the contaminants in the soils. Thermally enhanced SVE may require off-gas and/or residual liquid treatment. In situ vitrification uses heat to melt soil, destroying some organic compounds and encapsulating inorganics. An additional available in situ thermal treatment technology is thermal desorbsion, as well as the combination of thermal and electrokinetics (as proposed by ThermNet below).

SVE performance can be enhanced or improved by injecting heated air or steam into the contaminated soil through the injection wells. The heated air or steam helps to "loosen" some less volatile compounds from the soil. Researchers have done large-scale demonstrations of SVE with steam injection at several sites. In addition to heated air or steam, another enhancement of SVE is the use of radio-frequency (RF) heating to better vaporize or volatilize compounds in clay and silt-type soils. DAHL &

Associates Inc., and KAI Technologies Inc. have teamed to develop ThermNet, an in situ remediation service that enables accelerated remediation of subsurface contaminants in soil and groundwater. ThermNet combines radio frequency heating with one or more remedial technologies including soil vapor extraction, air sparging, pump and treat and bioremediation.[26] ThermNet delivers heat to subsurface media via electromagnetic radiation. Radio waves produced by a trailer-contained radio frequency generator and coupled subsurface applicators comprise the primary heating system. The heating mechanism does not rely on conductive properties of the soil or conventional limitations. Heat transfer occurs at the molecular level resulting in temperatures up to 300 degrees C. ThermNet can control and adapt the heating pattern to a variety of plume configurations and subsurface compositions. When paired with soil vapor extraction, vaporized, volatile and semi-volatile contaminants are removed to a mobile, modular remediation unit for treatment and discharge. Air sparging can be incorporated to enhance removal of contaminants. In addition, groundwater suppression via pump and treat can be employed to expose contaminants trapped beneath the water table, where appropriate.

EX SITU BIOREMEDIATION OF SOIL

Ex situ techniques can be faster, easier to control, and used to treat a wider range of contaminants and soil types than in situ techniques. However, they require excavation and treatment of the contaminated soil before and, sometimes, after the actual bioremediation step. Ex situ techniques include slurry-phase bioremediation and solid-phase bioremediation.

Slurry-phase bioremediation.

Contaminated soil is combined with water and other additives in a large tank called a "bioreactor" and mixed to keep the microorganisms -- which are already present in the soil -- in contact with the contaminants in the soil. Nutrients and oxygen are added, and conditions in the bioreactor are controlled to create the optimum environment for the microorganisms to degrade the contaminants. Upon completion of the treatment, the water is removed from the solids, which are disposed of or treated further if they still contain pollutants. Slurry-phase biological treatment can be a relatively rapid process compared to other biological treatment processes, particularly for contaminated clays. The success of the process is highly dependent on the specific soil and chemical properties of the contaminated material. This technology is particularly useful where rapid remediation is a high priority. At the French Ltd. Superfund site in Texas, slurry-phase bioremediation was used to treat 300,000 tons of lagoon sediment and tar-like sludge contaminated with volatile organic compounds, semi-volatile organic compounds, metals, and pentachlorophenol. Over a period of 11 months, the treatment system was able to meet the cleanup goals set by EPA.

Landfarming

In this relatively simple treatment method, contaminated soils are excavated and spread on a pad with a built-in system to collect any or contaminated liquids that seep out of contaminant soaked soil. The soils are periodically turned over to mix air into the waste. Moisture and nutrients are controlled to

enhance bioremediation. The length of time for bioremediation to occur will be longer if nutrients, oxygen or temperature are not properly controlled. In some cases, reduction of contaminant concentrations actually may be attributed more to volatilization than biodegradation. At the Scott Lumber Company Superfund site in Missouri, 16,000 tons of soils contaminated with polyaromatic hydrocarbons (PAHs) were biologically treated (70% reduction) using land treatment application.

EX SITU CHEMICAL PHYSICAL/CHEMICAL TREATMENT

The main advantage of ex situ treatment is that it generally requires shorter time periods than in situ treatment, and there is more certainty about the uniformity of treatment because of the ability to homogenize, screen, and continuously mix the soil. Ex situ treatment, however, requires excavation of soils, leading to increased costs and engineering for equipment, possible permitting, and material handling/worker exposure conditions. Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy, separate, or immobilize the contamination. Dehalogenation uses destruction technologies. Soil washing, SVE, and solvent extraction are separation techniques, and Solidification/Stabilization (S/S) is an immobilization technique. Physical/chemical treatment is typically cost effective and can be completed in short time periods (in comparison with biological treatment). Equipment is readily available and is not engineering or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits.

Chemical Dehalogenation

Chemical dehalogenation is a chemical process to remove halogens (usually chlorine) from a chemical contaminant, rendering it less hazardous. Halogens include chlorine, bromine, iodine, and fluorine. Polychlorinated biphenyl's (PCB's) are halogenated compounds that once were used in high voltage electrical transformers. Halogenated compounds also are commonly used in water treatment, swimming pool chemicals, and plastic piping and textile production. The chemical dehalogenation process can be used on common halogenated contaminants such as PCBs and dioxins that are usually found in soil and oils.

A promising innovative technology in this area of chemical dehalogenation, the base-catalyzed decomposition (BCD) process, was developed by the U.S. Environmental Protection Agency as a clean, inexpensive way to remediate liquids, sludge, soil, and sediment contaminated with chlorinated organic compounds, especially PCB's. Contaminated soil is excavated and screened to remove debris and large particles, then crushed and mixed with sodium bicarbonate. This mixture is heated in a reactor. The heat separates the halogenated compounds from the soil by evaporation. The soil left behind is removed from the reactor and can be returned to the site. The contaminated gases, condensed into a liquid form, pass into a liquid-phase reactor. The dehalogenation reaction occurs when several chemicals are mixed with the condensed contaminants and heated in the reactor. The resulting liquid mixture can be incinerated or treated by other technologies and recycled. The BCD process components are easily transported and

safely operated. The process employs off-the-shelf equipment and requires less time and space to mobilize, set up, and take down than an incinerator—which is a common alternative treatment for PCB-contaminated wastes.

Soil Washing

Soil Washing is a technology that uses liquids (usually water, sometimes combined with chemical additives) and a mechanical process to scrub soils. This scrubbing removes hazardous contaminants and concentrates them into a smaller volume. Hazardous contaminants tend to bind, chemically or physically, to silt and clay. Silt and clay, in turn, bind to sand and gravel particles. The soil washing process separates the contaminated fine soil (silt and clay) from the coarse soil (sand and gravel). When completed, the smaller volume of soil, which contains the majority of the fine silt and clay particles, can be further treated by other methods (such as incineration or bioremediation) or disposed of according to state and federal regulations. The clean, larger volume of soil is not toxic and can be used as backfill. The equipment is transportable so that the process can be conducted at the site. At the King of Prussia site in New Jersey, soil washing was used to remove metal contamination from 19,000 tons of soil and sludge at a former industrial waste reprocessing facility. The soil washing process was able to clean the materials to meet clean-up goals for eleven metals. For example, chromium levels went from 8,000 milligrams chromium per kilogram of soil (mg/kg) to 480 mg/kg.

Solvent Extraction uses a solvent (a fluid that can dissolve another substance) to separate or remove hazardous organic contaminants from sludges, sediments, or soil. Solvent extraction does not destroy contaminants. It concentrates them so they can be more easily recycled or destroyed by another technology. When the soil enters an extractor (a tank where the contaminated soil is mixed with the solvent), the soil is separated into three components. Each component can then be individually treated or disposed of more cost effectively. The entire process is conducted on-site and begins by excavating the contaminated soil and moving it to a staging area where it is prepared for treatment. The soil is placed in the extractor. The solvent is added to the extractor, and the soil and solvent are mixed together. Consequently, the organic contaminants dissolve into the solvent. The separation process occurs next. The contaminants are separated from the solvent either by changing the pressure and temperature, by using a second solvent to pull the first solvent out of the solvent/contaminant mixture, or by other physical separation processes. At the completion of this step, concentrated contaminants result. Concentrated contaminants are removed during the separation process, and the solvent is sent to a holding tank for reuse.

IN SITU BIOREMEDIATION OF GROUNDWATER

In Situ Bioremediation of Groundwater speeds the natural biodegradation process that take place in the water-soaked underground region that lies below the water table. For sites at which both the soil and groundwater are contaminated, this single technology is effective at treating both. Generally, an in situ groundwater bioremediation system consists of an extraction well to remove groundwater from the

ground, an above-ground water treatment system where nutrients and an oxygen source may be added to the contaminated groundwater, and injection wells to return the "conditioned" groundwater to the subsurface where the microorganisms degrade the contaminants.

Treatment Walls

There are an estimated 5,000 Department of Defense, Department of Energy, and Superfund sites contaminated with chlorinated solvents. Probably 10 to 20 percent of these have the right conditions to use treatment walls. Treatment Walls are structures installed underground to treat contaminated ground water. Treatment walls also are useful at sites contaminated with metals and radioactive contaminants. Treatment walls are put in place by constructing a giant trench across the flow path of contaminated ground water and filling it with reactive fillings (usually iron). As the ground water passes through the treatment wall, the contaminants are either trapped by the treatment wall or transformed into harmless substances that flow out of the wall. The specific filling chosen for a wall is based on the types of contaminants found at the site. The major advantage of treatment walls over traditional treatment methods such as pump-and-treat is that they are passive systems that treat the contaminants in place. There is no need to dig up contaminated soil or pump out contaminated water, there are no parts to break, no need for electricity, and, since there is no equipment on the surface, the property can be put to productive use while it is being cleaned up. Engineers estimate at least a 50% cost savings using treatment walls instead of pumping out contaminated ground water.

At a former semiconductor-manufacturing site in Sunnyvale, California, 220 tons of iron shavings were used to fill a reactive treatment wall that has been breaking down TCE since December 1994. The above ground equipment that was part of a previously installed pump-and-treat system was removed and the site has been leased to another company that uses it as a parking lot. At individual installations the Army has reaped the benefit of strong partnerships in the past with regulators and the public. Innovative technologies have proven to save valuable restoration resources. At Twin Cities Army Ammunition Plant (TCAAP) in New Brighton, Minnesota, several years of effort culminated in the signing of the installation-wide Record of Decision (ROD), at a cost saving of almost $4M. These funds are available to the Army's cleanup program for future cost restoration efforts. At Hunter Army Airfield in Georgia, the Army will recommend implementation of a monitored natural attenuation remedy instead of a costly pump-and-treat system, as part of an initiative to reassess planned groundwater treatment systems. If accepted by the environmental regulators and the local community, this recommendation could result in savings of $5 million. A separate study of existing and proposed groundwater remediation systems at Riverbank Army Ammunition Plant in California resulted in a 40 percent reduction in operating costs and annual savings of $1.2 million dollars.

PARTNERSHIP WITH INDUSTRY

The DUSD (ES) recently commented that

> "A key gap in bringing new technologies into use was in demonstrating and validating their effectiveness. We identified this gap several years ago, and filled it by establishing

the Environmental Security Technology Certification Program (ESTCP). Since that time, SERDP & ESTCP have opened the proposal solicitation to industry. Roughly 50% of SERDP & ESTCP projects are developed and demonstrated by industry. This has been another important step in developing technologies that can make it from the lab to market. As we move to develop and test new environmental technologies we must look towards commercialization from the outset. We must be vigilant about working in lock step with industry. In the brief history of SERDP & ESTCP they have supported the commercialization of approximately twenty and thirty technologies. These range from sensor technologies to processing technologies."[27]

A RAND study of the environmental research at four major corporations (DuPont, Intel, Montsanto, and Xerox) revealed that the government does not know much about the views of industry with regard to this important issue.[28]The companies are not very interested in remediation, monitoring, and control technologies, because these technology areas are less likely to meet the corporate objectives of yield improvement, emission reduction, resource efficiency, pollution reduction and recycling. These environmental issues (and the R&D resources) will have a direct impact on the company's ability to provide a service to the customer. The companies sought to limit the amount invested in remediation technologies, hoping that the pollution prevention orientation of the technologies of interest would lessen the future requirement for remediation and control technologies. Even though all four companies expressed interest in public-private partnerships, they could not agree on the priorities and focus of the research efforts. Nonetheless, they did provide some direction for government involvement. Specifically they wanted the government to provide leadership on national environmental technological priorities, continue to invest in science and technology (establish closer ties to academia), and take action to protect intellectual property rights of the companies. More work needs to be done in this area.

CONCLUSION

DOD continues to encounter new issues and challenges in the Environmental Restoration Program. In response to the overall decreasing budget, the increase in oversight by the EPA, and the amount of contaminated land the DOD must eventually remediate unit commanders must begin to push the envelope to incorporate innovative technologies in their environmental studies, investigations, and risk assessments. The examples cited in the technology discussion clearly demonstrate that it is more cost-effective to utilize innovative technologies, than return to the old "pump and treat" or "dig and bury" technology we used until the early 80's. DOD must issue policies and guidance, create criteria for prioritizing activities, reallocate resources, and develop management and oversight systems to gain the efficiencies realized by utilizing innovative environmental restoration technologies. Incorporation of these innovative technologies becomes especially critical at closing BRAC sites, where the government land will soon be turned over to communities for reuse. Both the base and the local redevelopment authority have a vested interest in ensuring the right technology is chosen for each restoration project. The installation must partner with the community to develop long-lasting remediation techniques that the community can live with, after the Army is gone. Only by establishing a strong partnership will both interests be protected. The Army must continue with its push to expedite the clean up of hazardous waste sites across the

country, caused by decades of operations. We must continue to pursue new environmental initiatives, and streamline the clean up process. Wherever possible, we should incorporate new and innovative remediation technology into the Remedial Investigations and Feasibility Studies.

Since the information explosion caused by the Internet now allows almost anybody to access huge amounts of information, the Army must update the information currently contained on its environmental databases, so the most current information is available. As discussed in the earlier sections, much of the information is dated due to the speed of new innovation design. The technology information that is over five years old should be updated and kept current. Those organizations that currently maintain separate information databases must cooperate together to provide the commander with the most up to date information possible. Recommend the US AEC provide the Army's focal point for this information fusion.

We must develop a strong partnership initiative between the Services, private industry, the state and federal regulators, and federal environmental agencies. Ms. Goodman clearly articulated the need for DOD and industry to establish partnerships as we both execute our missions as environmental stewards of our resources.

While the descriptive listings I provided of innovative technologies only scratches the surface of each one, additional information is available on the specific sites listed. Recommend commanders become involved with their program managers, and understand what additional sources of information are available to use when conducting risk analysis on a specific site.

Word Count: 8,041

ENDNOTES

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